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D-branes, fluxes and chirality

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Abstract

We describe a topological effect on configurations of D-branes in the presence of NS-NS and RR field strength fluxes. The fluxes induce the appearance of chiral anomalies on lower dimensional submanifolds of the D-brane worldvolume. This anomaly is not associated to a dynamical chiral fermion degree of freedom, but rather should be regarded as an explicit flux-induced anomalous term (Wess-Zumino term) in the action. The anomaly is cancelled by an inflow mechanism, which exploits the fact that fluxes can act as sources of RR fields. We discuss several applications of this flux-induced anomaly; among others, its role in understanding anomaly cancellation in compactifications with D-branes and fluxes, and the possibility of phase transitions where a chiral fermion disappears from the D-brane world-volume spectrum, being replaced by an explicit Wess-Zumino term. We comment on the relation among different mechanisms to obtain four-dimensional chirality in string theory.

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1 Introduction

Compactifications of type II string theory / M-theory with field strength fluxes turned on (see e.g. [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11]) are an interesting class of constructions which may shed new light on several questions of phenomenological relevance. For instance, the observation that fluxes lead to warped internal metric suggests the models may be used to generate exponential hierarchies [5, 7, 9], following the proposal in [12], yielding a possible solution for the hierarchy of scales in particle physics. On the other hand, the observation that the presence of fluxes induces tree-level potential terms for diverse moduli [4, 6], including even the dilaton, provides a possible canonical mechanism to stabilize them [5, 9, 10].

Several properties of type II compactifications with fluxes have been studied recently. In particular, the consistency conditions for the configurations, the amount of supersymmetry preserved, and also the effective action for the closed string sector fields (e.g. potential for moduli). However the physics of D-branes, namely of open string sectors, in compactifications with fluxes has been much less analyzed. There are several indications that such physics is nevertheless extremely interesting; in fact D-branes in the presence of fluxes present interesting phenomena, for instance the dielectric effect [13]. Their systematic analysis is however difficult given the incomplete knowledge of non-abelian D-brane actions, and the difficulties to obtain worldsheet results in situations with RR fluxes.

In this paper we center on a particular effect whose analysis is relatively simple, since it involves only topological couplings. Yet the consequences of the effect are extremely interesting. In Section 2, we show that, in the presence of suitable NS-NS and RR field strength fluxes, D-branes develop a chiral anomaly localized at lower-dimensional submanifolds of their volume. This is derived by first showing there exists an anomaly inflow from the D-brane world-volume towards such lower-dimensional slices, which signal the existence of an anomaly source. The source of the anomaly is not, contrary to other familiar situations, a chiral fermion degree of freedom, but rather an explicit anomalous interaction developed by the D-brane in the presence of the fluxes.

In Section 3 we present two applications of this effect. It plays a key role in understanding anomaly cancellation on the world-volume of D-brane probes in certain configurations with fluxes, and of cancellation of anomalies in chiral compactifications with fluxes. In Section 4 we discuss brane/flux transitions and use them to generate transitions on D-brane world-volumes, in which a dynamical chiral fermion disappears from the spectrum, leaving behind an explicit Wess-Zumino term. Section 5 discusses

how to generate global gauge anomalies using fluxes. Section 6 concludes with a discussion of the interrelation among different mechanisms to generate four-dimensional chirality in string theory.

2 Chirality from fluxes

In this section we discuss the effect of flux-induced anomaly on D-branes in the presence of fluxes. We start with a review of the anomaly inflow mechanism in Section 2.1. In Section 2.2 we show that in configurations of D-branes and NS-NS and RR fluxes, there exists an inflow of anomaly from the D-brane worldvolume towards lower dimensional slices of its volume. The inflow signals the existence of an anomaly source, which we identify as an explicit anomalous interaction, rather than a dynamical fermion degree of freedom.

2.1 The anomaly inflow mechanism

Let us give a simplified review of the anomaly inflow mechanism for D-branes, as discussed in [14]. Consider a D-brane, which couples to the RR fields through the action

$$S_{Dp} = \int_{Dp} \mathcal{C} \wedge Y(F, R) \quad (2.1)$$

where \mathcal{C} is a formal sum of RR forms of different degrees, and Y is a closed gauge invariant form depending on the worldvolume gauge field strength and curvature, in fact

$$Y = \text{ch}(F) \hat{A}(R)^{1/2} \quad (2.2)$$

where ch is the Chern character and \hat{A} is the A-roof genus. In what follows, wedge products will be implicit.

We will be interested in situations where the RR fields have a source (different from the D-brane itself), so that the field strength \mathcal{G} obeys

$$d\mathcal{G} = \mathcal{Z} \quad (2.3)$$

where \mathcal{Z} is a source form (in fact a formal sum of them), which is often a bump form, a delta-function localized on the core of the source (typically, but not necessarily, a D-brane).

In this situation, \mathcal{C} is not well defined, so the D-brane coupling (2.1) is better defined by

$$S_{Dp} = \int_{Dp} \mathcal{G} Y^{(0)}(F, R) \quad (2.4)$$

where we have used the Wess-Zumino descent relation notation, i.e. for a closed gauge invariant form Y , we define $Y = dY^{(0)}$, $\delta Y^{(0)} = dY^{(1)}$, where δ represents a gauge variation.

In this situation, the action (2.4) is not gauge invariant, its gauge variation is given by

$$\delta S_{Dp} = \int_{Dp} \mathcal{G} \delta Y^{(0)}(F, R) = \int_{Dp} d\mathcal{G} Y^{(1)}(F, R) = \int_{Dp} \mathcal{Z} Y^{(1)}(F, R) \quad (2.5)$$

Recalling the familiar interpretation of $Y^{(1)}$ as the anomaly descending from an anomaly polynomial $Y(F, R)$, it is useful to interpret this last expression by saying that there exists an inflow of chiral anomaly from the Dp -brane volume towards the core of the source (or rather towards its intersection with the Dp -brane volume), with density given by the source form \mathcal{Z} . That is the Dp -brane action is no longer gauge invariant, and its gauge variation is localized on the core of \mathcal{Z} . If \mathcal{Z} is not bumpy the inflow at each lower dimensional slice is proportional to the magnitude of \mathcal{Z} .

This lack of gauge invariance must be compensated by a counteracting effect, arising at the core of the source Z . As we discuss below, the usual situation is that a dynamical chiral fermion arises, whose anomaly is cancelled by this inflow. In the following section we argue there exist situations where no such dynamical fermion arises, but instead there exists an explicit Wess-Zumino interaction on the Dp -brane world-volume.

A familiar situation where the anomaly inflow is cancelled by the appearance of a dynamical chiral fermion degree of freedom is intersecting D-branes, see [15]. For concreteness consider two stacks of D6-branes intersecting over a four-dimensional subspace of their world-volumes, Fig 1a. By a slight generalization of the above argument (see [14]), the world-volume action of each D6-brane stack is not gauge invariant due to the presence of the other D6-brane stack, which acts as a source. This results in an overall gauge variation

$$\delta S_{D6_1+D6_2} = \int [Y(F_1, R) Y(F_2, R)]^{(1)} \delta_I \quad (2.6)$$

where δ_I is a bump 6-form localized at the four-dimensional intersection, and F_1, F_2 are the curvatures of the gauge bundles on the D6-brane stacks. Namely there is an inflow of chiral anomaly from the two sets of D6-branes towards their intersection.